A Comparative Study of Juxtaposed Lake Systems Underlain by Differing Bedrock along the Minnesota-Ontario Border

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The region of study spans the international border of Minnesota and Canada and lies within the Boundary Waters Canoe Area and Quetico Provincial Park between 48'00" and 48'15" lat., 91'35" and 91'55" long. The contact zone between the Vermillion Batholith and a metasedimentary unit to the south runs roughly along the international border. Lakes on the U.S.A. side of the contact are underlain by the metasedimentary rocks, are eutrophic (highly productive) and exhibit a yellow-brown staining, while lakes underlain by the granite batholithic, are mesotrophic to oligiotrophic, and distinctly more clear than the metasedimentary lakes and green in color. With little exception, lakes sampled within the separate lithologies show the color distinction. The following schematic cross section shows this apparently simple yet, inherently complex relationship.

In determining the reason for the contrasting lake environments, a relationship apparently determined by bedrock disparities, several assumptions and facts about the study area need to be clarified.

1. Precipitation over the area is assumed to be uniform in composition and amount.
2. All of the lake basins were formed during the Pleistocene glaciation and, consequently, have undergone similar periods of maturation.
3. With the exception of logging in the area, the human induced degradation within the watershed of the region, which spans the international wilderness border, is extremely minute and is assumed not to be a determining factor in the differences observed.
4. The most important way in which the water chemistry differs with respect to lithology is in the Dissolved Organic Carbon content (DOC). The concentration of DOC is directly correlated with the recorded color. (See graph: Color vs. DOC)

Upon the assumption of the above, it follows quite reasonably that the cause of the contrasting water composition/color relationship is rooted in the basic environmental disparities imposed on the area by the disparity in the bedrock.

HYPOTHESIS A

Comparison of the chemical analysis of the lake water sampled leads to the first hypothesis based solely on differences in chemistry imparted on the lake water by the bedrock. A buffering capacity disparity exists between the juxtaposed lake systems which renders the batholithic lakes more susceptible to cultural acidification. Two separate studies, a report coordinated by The Acid Rain Foundation, and EPA paper 600/3-80-044, address the threat of cultural acidification on lakes in the Northern Lake States, and specifically mention the Boundary Waters Canoe Area and Quetico Provincial Park as susceptible areas, already affected by acidic precipitation. Atmospheric acid sulfate loadings in the BWCA, they say, are at levels associated with severe lake acidification in Scandinavian countries and precipitation in the near vicinity is sometimes strongly acid. The mean annual pH of precipitation in the area is at the level where serious damage begins.

The batholithic lakes within the study area have the symptoms of minor acidification and may be undergoing a process of "self-accelerating oligiotrophication," which has lead to the demise of lakes to the east in the similarly remote Adirondacks. Basically, acidification causes an inhibition of microbial decomposition, which leads to lower trophic levels and consequently, clearer water, more devoid of organic matter. (Nichols et al. 1985) found that affected lakes show a pattern of decreasing alkalinity with respect to Ca+Mg content, along with an increase in SO_4. Batholithic lakes have these symptoms of acidification, (see graph: Alkalinity vs.Ca+Mg) The metasedimentary lakes are also susceptible, as can be seen from the plotted field of the samples from the U.S lakes. (Alkalinity vs. Ca+Mg graph) Berner and Berner (1987) point out that eutrophic lakes, (metasedimentary lakes), are protected against acidification by bacterial processes within the lake, which do not occur in noneutrophic lakes, (batholithic lakes). These processes reduce the SO_4 and NO_3 to safer, non-acidifying forms and produce HCO_4 alkalinity which buffers the lake to acidic input. The pH levels measured during the summer of '88 do not show an acidification of batholithic lakes. It is possible, however, that lake processes during the summer months mask the problem and that acidic snowmelt during the spring leads to a highly acidic layer of water which is very harmful to the lake and its biota, a phenomenon mentioned in all three of the previously cited studies. This hypothesis is valid and evidenced by the information available from the past summer's research. More extensive sampling over a longer period would be necessary to gain further evidence showing to what extent these chemically based differences in buffering capacity have lead to the contrast in color between the dissimilar lakes. However, there are other significant differences between the lake systems which may be equally important, and yet, not exclusive of the buffering hypothesis.

The remaining hypotheses are not solely based on chemical differences between the lithologies, but rather the differing physical attributes that have lead to distinctly different weathering and maturation scenarios within the separate lake systems. The differing lake depths on either side of the contact may be due to differing pre-glacial weathering patterns that have caused dissimilar post-glacial topographies within the two lithologies. Consequently this led to the formation of dissimilar lake basin depths, which have ultimately led to differing trophic levels that correspond to bedrock type.

HYPOTHESIS B

A glacier is only efficient enough to remove pre-glacially loosened material. Differences in crystal size and type, coupled with dissimilar permeabilities and structural features between the two lithologies, may have led to the present disparity between the depths of the lake basins within respective rock types. The advance of the glacier may have excavated deeper basins within the batholith and shallow basins within the metasediments. Perhaps the outlets of the batholithic lakes are topographically high in relation to their bottoms. Another possibility is that there has been a disparity in the lake basin filling rates corresponding to rock type which has lead to the lake depth discrimination and, consequently, the contrasting trophic levels. This theory is evidenced by the simple fact that metasedimentary lakes have more ions in solution, a sign of a greater amount of weathering. Hypothesis B is also valid and even may have contributed to the affects on the system by the acidification process. However, the huge Crooked Lake, which forms a water boundary between Minnesota and Ontario (along the contact), contains mixed water and is significantly colored, has depths up to 20m. This leads to the idea that there is a contribution from the metasedimentary lakes which is effective enough to color the mixed lake, especially in its southern bays, into which metasedimentary water flows.

HYPOTHESIS C

The third hypothesis is based on the maturation disparity theory. There is a significantly greater amount of swamp/marsh/bog area within the metasediments, a phenomenon which probably is rooted in the contrasting filling rates of the differing lithologies. There may be a greater depth of soil over the metasedimentary bedrock, as well. This difference in watershed physics and chemistry probably results in a greater fraction of allocthonous humic material entering the metasedimentary lake in solution from the runoff and ground water. That fraction of the humic material that comes from outside of the lake, from bogs and soils within the watershed of the lake, is called allocthonous as opposed to autochthonous material which is derived from processes within the lake itself. Interestingly, allocthonous humic matter is highly colored, while autochthonous matter, such as phytoplankton, is colorless.

All of the theories mentioned in these hypotheses are probably at work within the study region. To determine the extent to which one of the above hypotheses is most significant in the determination of this relationship, would require more intensive sampling over a longer period of time.

REFERENCES

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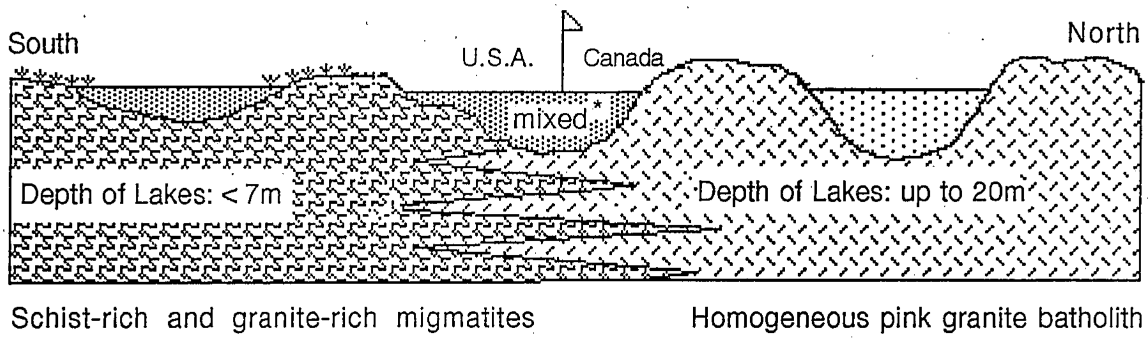
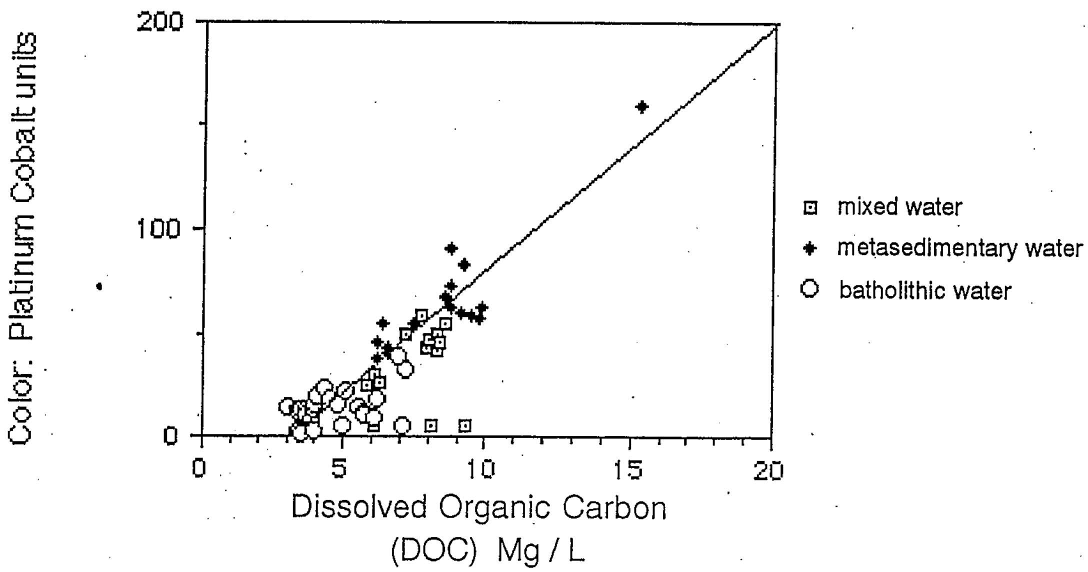
Schematic Cross Section

Metasedimentary Bedrock	Granitic Bedrock
Water Color: Brown, "tea-colored"	Water Color: Clear and green
Dissolved Organic Carbon (DOC) : 8 mg / l	DOC: 4 Mg / l
Ca+Mg: 205 ueq / l	Ca+Mg: 150 ueq /l (poorly buffered)
More swamp/ bog area (more allocthonous humic contribution)	Less swamp/ bog area



* mixed lakes exhibit characteristic brown staining

Color vs. Dissolved Organic Carbon



Alkalinity vs. Ca+Mg